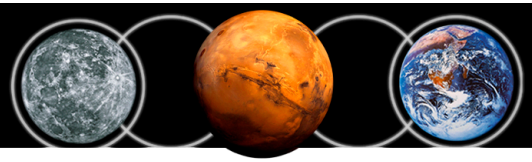


Real-Time Mission Management in Next Generation Spacecraft: Human Factors Challenges

Robert S. McCann, Ph.D.
Jeffrey McCandless, Ph.D.
&
The ISIS Lab Team

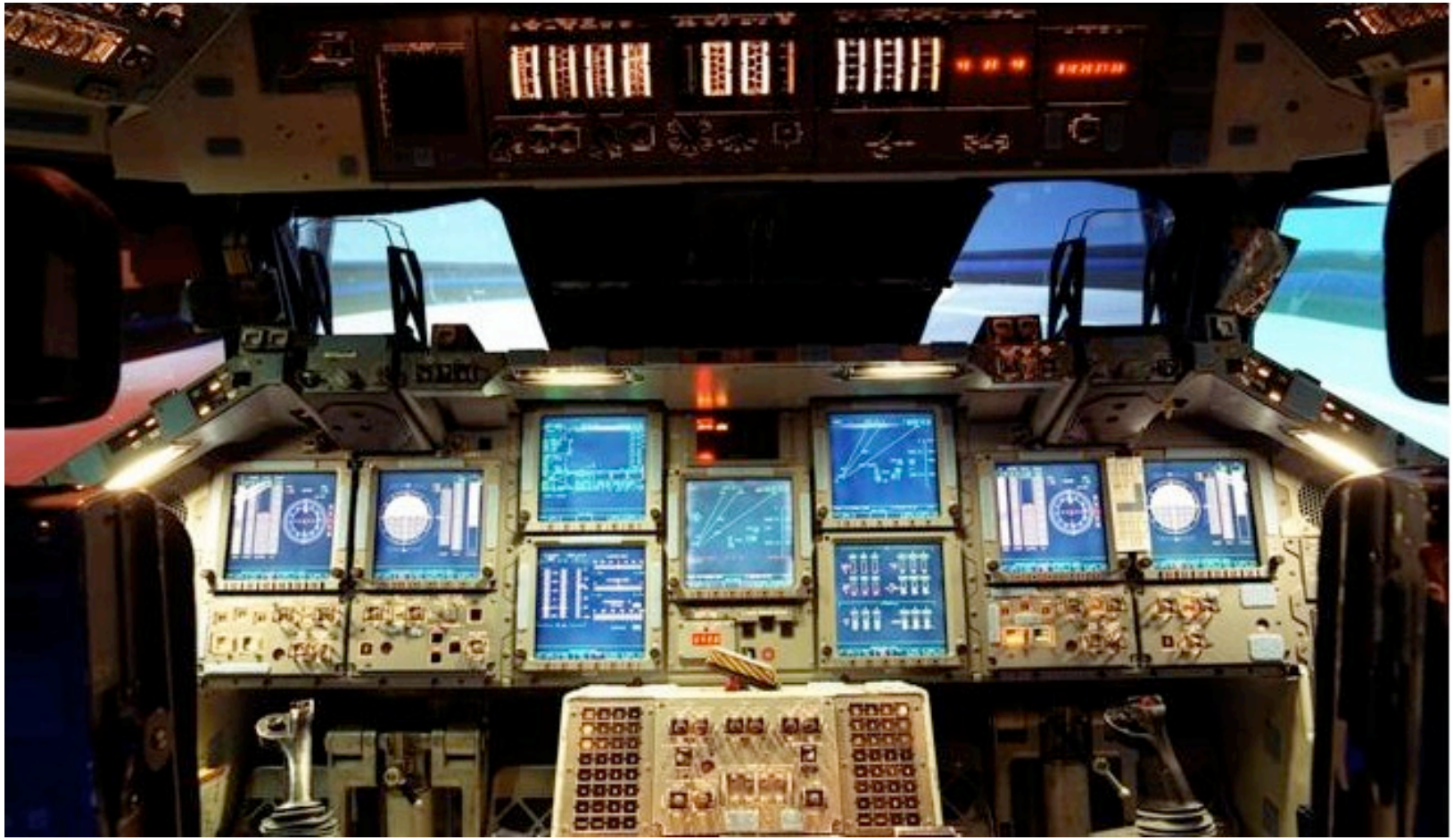
Human Factors Research and Technologies Division
NASA Ames Research Center
Moffett Field CA

- Shuttle Most complex flight vehicle ever designed
  - Experimental: First Generation Design
- Large number of *very complex* engineering systems:
  - Propulsion
  - Electrical
  - Life Support
  - Navigation
  - Communication
- Operating Conditions:
  - Extremely Harsh & Dynamic
- Result:
  - Systems malfunctions are a ***real and present danger*** to crew safety and mission success

- Each shuttle system extensively instrumented:

- Scores of sensors measuring various operational parameters:
    - pressures
    - temperatures
    - flow rates
    - RPMs

- Must be monitored continuously to:
    - Maintain awareness of
        - Systems mode
        - System functioning



- Problem:
- Insufficient display real estate in the cockpit
- Not enough pairs of eyes to process it (2 crew + 1 mission specialist)

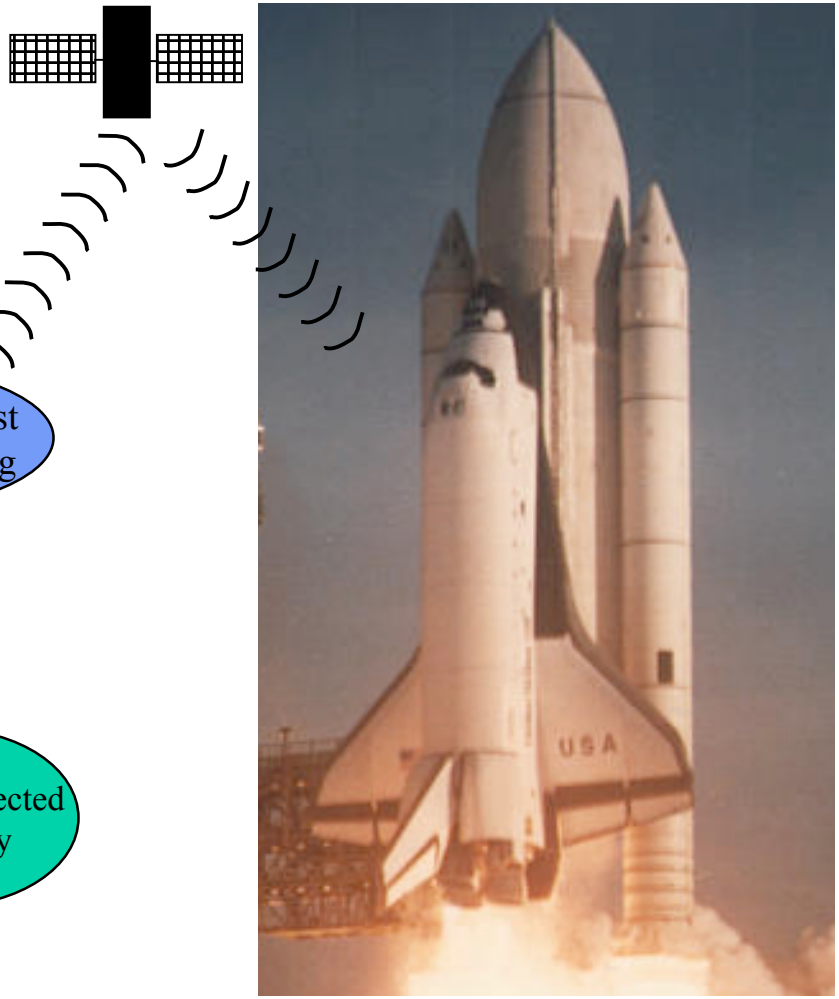
- Approximately 100 subject matter experts at Mission Control

- dedicated group for each system

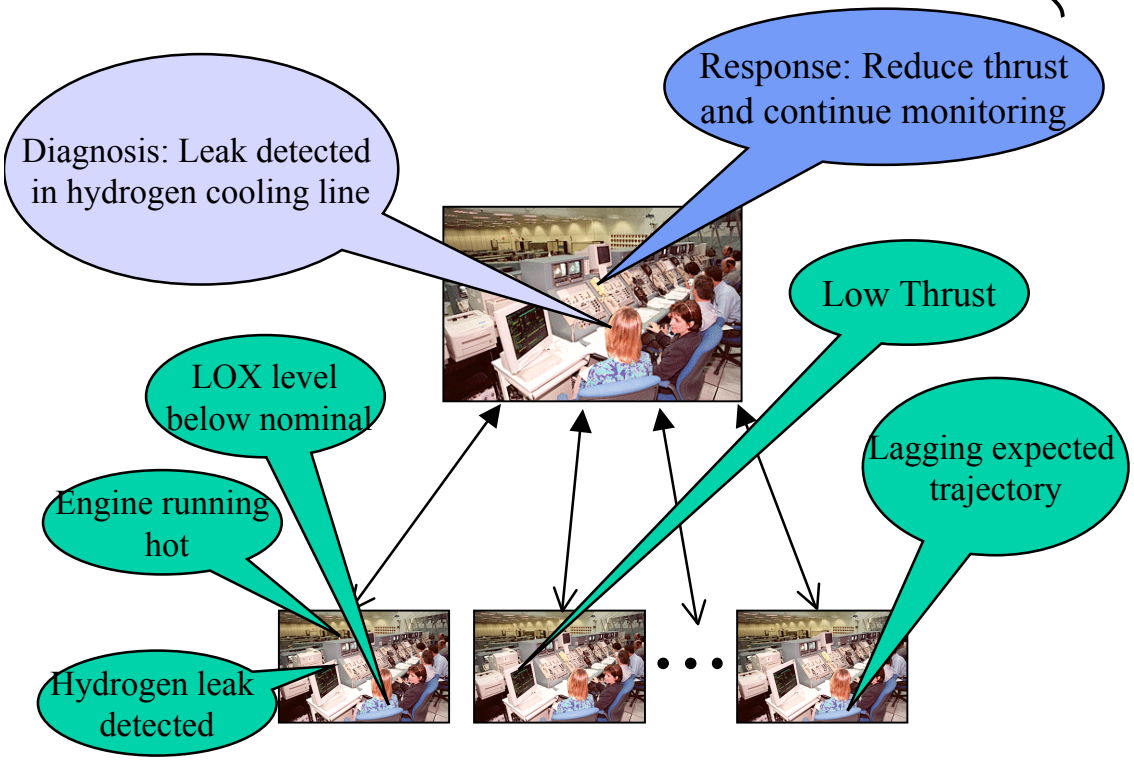
- monitor telemetered information from vehicle

- work real-time mission management in tight collaboration with the crew

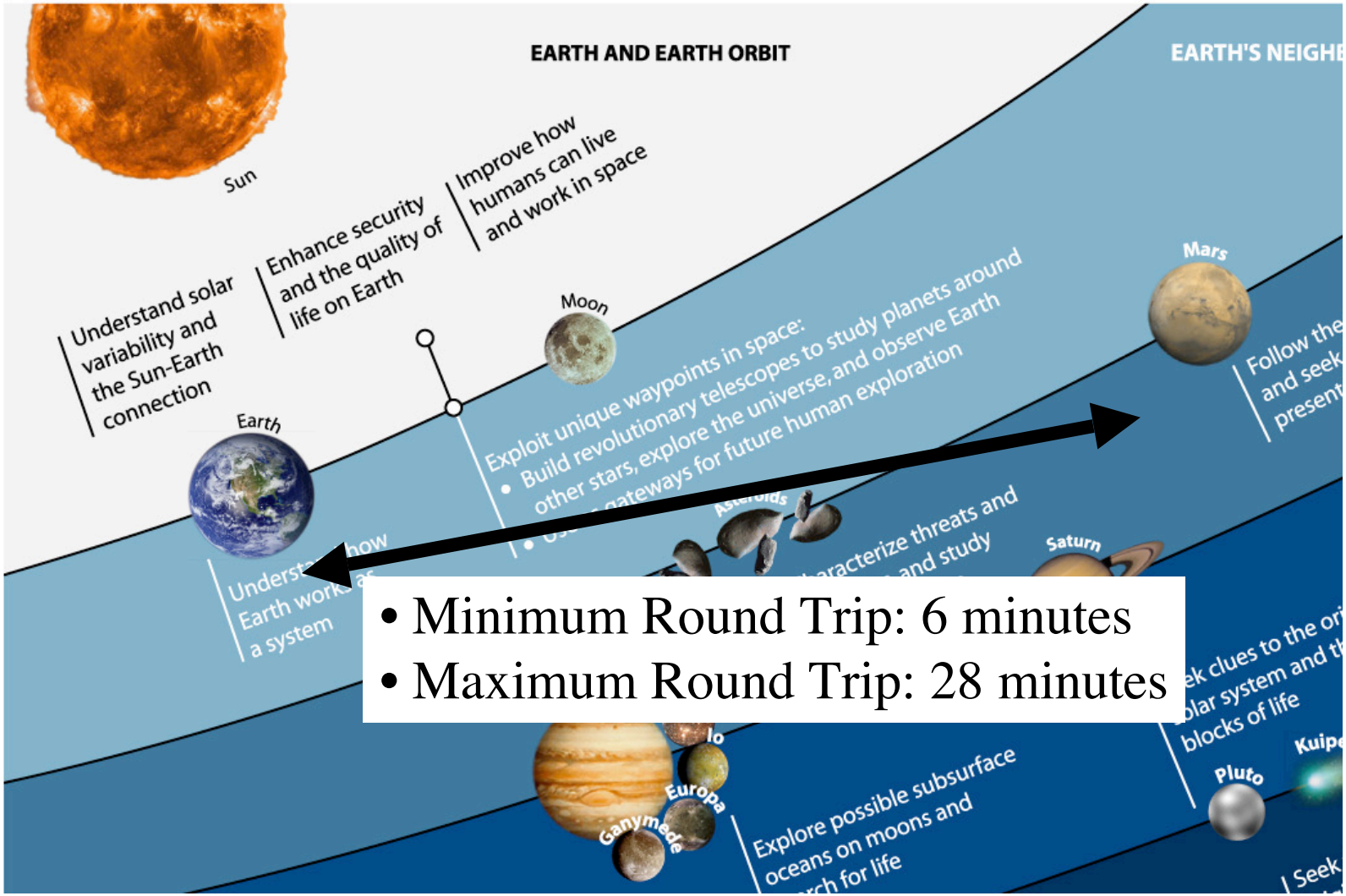
Propulsion ECLSS GN&C



Control room hierarchy

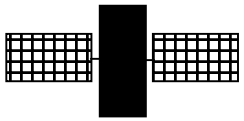


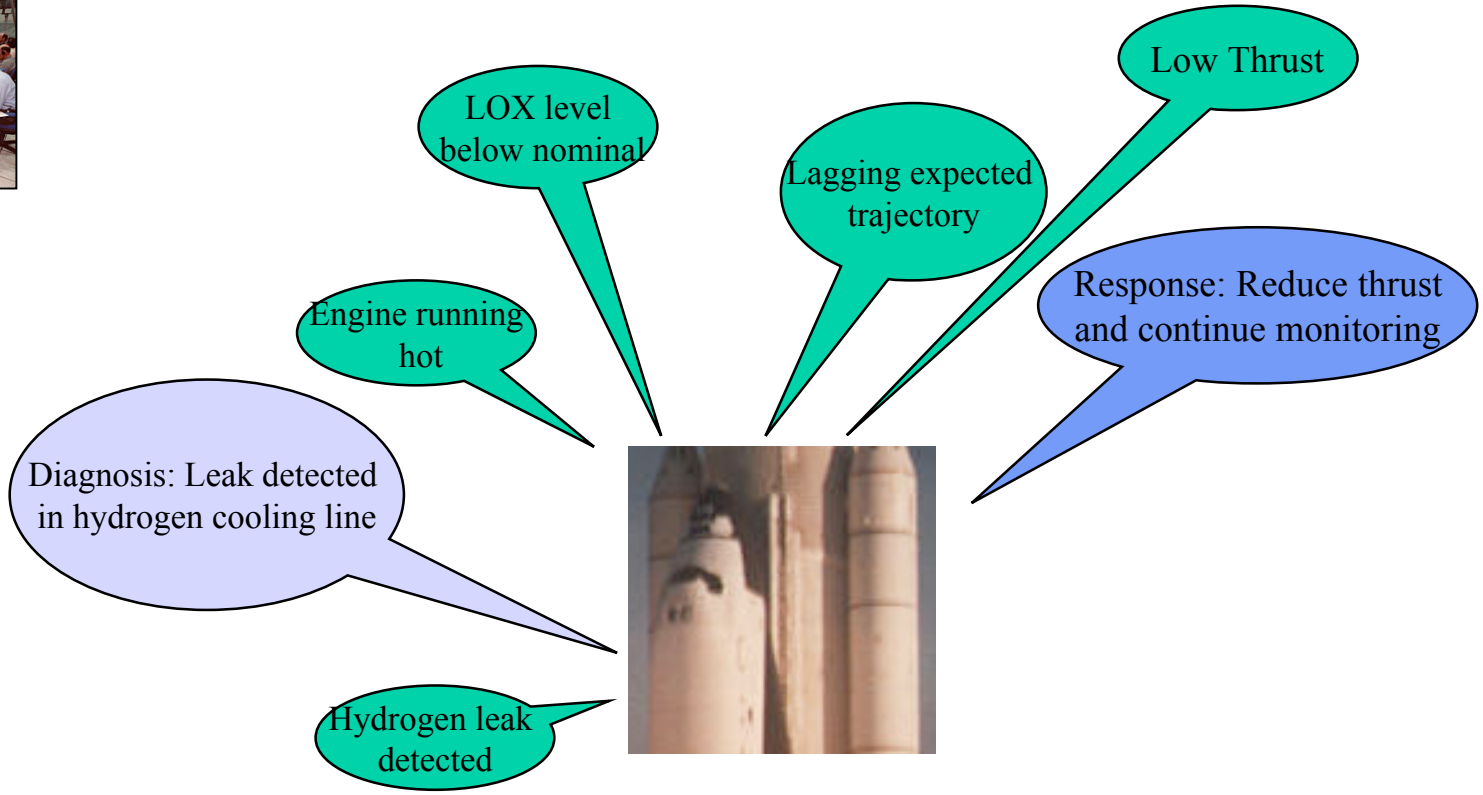
Tightly coupled Crew-Ground Coordination



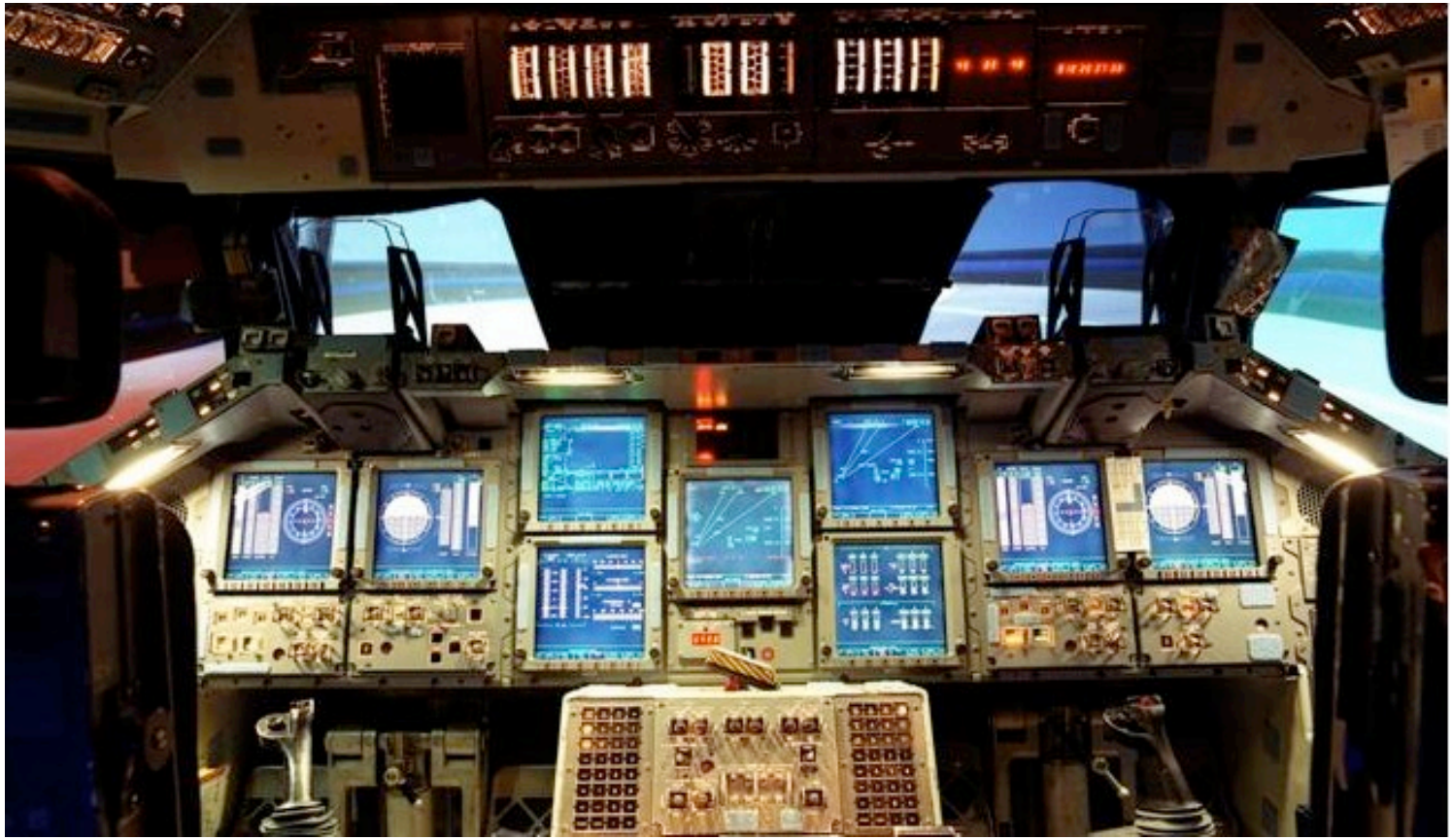
- Tightly-coupled crew-ground coordination not possible

- More autonomous concept of operations required





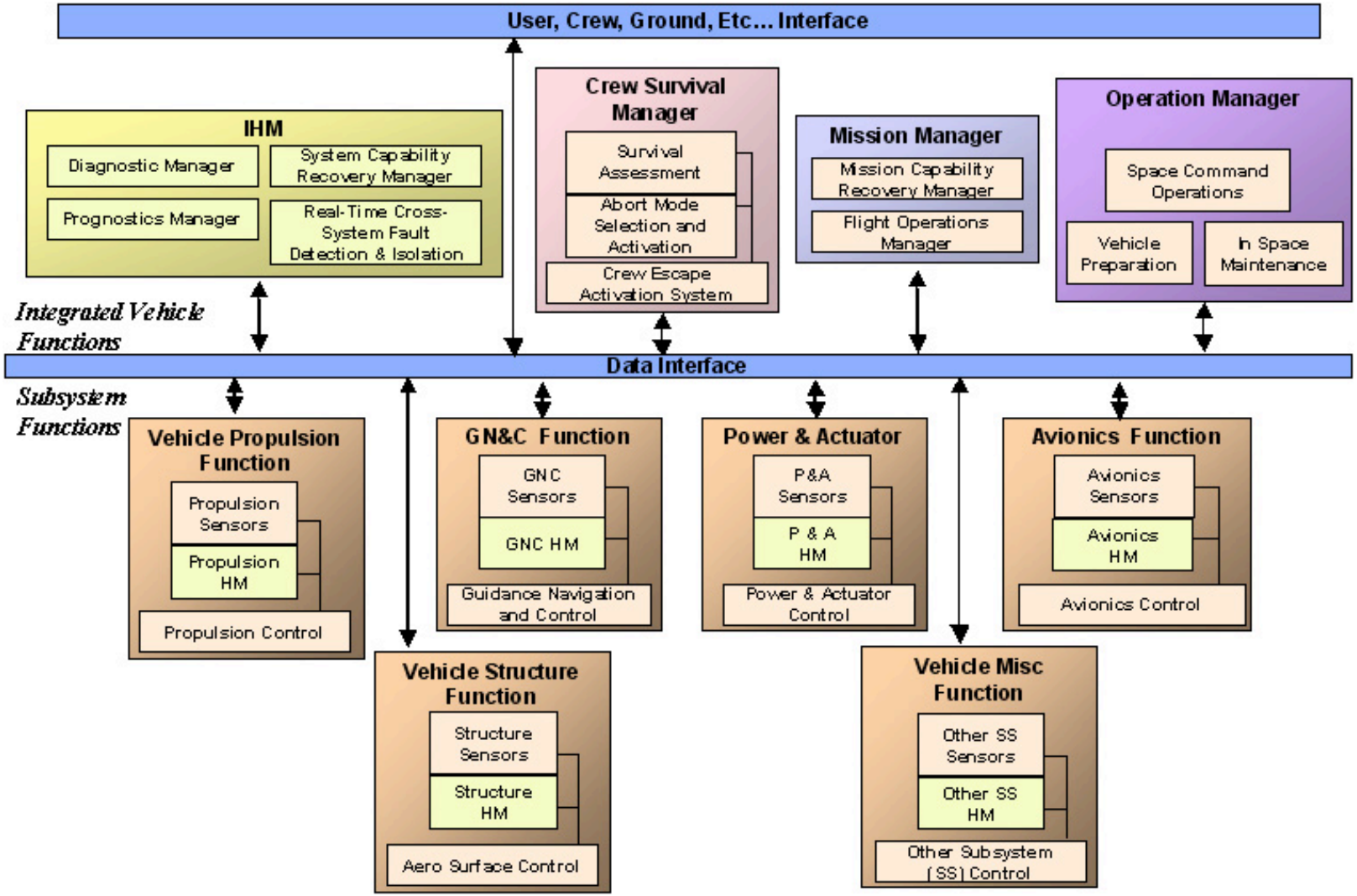
- Onboard mission management capabilities have to be enhanced



- Fundamental CEV Design Problem:
- How to enhance onboard mission management capabilities given the:
  - Limited display real estate in the cockpit
  - Limited pairs of eyes onboard the vehicle

- A solution in two parts:

  Part 1: Enhanced onboard automation



- Part 2: Maximize Crew Mission Management Capabilities
  - Optimize Human-Automation Interactions
    - Define appropriate Human-machine Functional Allocation
      - Prevent well known human factors pitfalls
        - e.g., The "OOTLUF" Problem
    - Design and evaluate user interfaces to support selected functional allocation
      - Avoiding "Clumsy Automation"
  - Make greater use of human information processing capabilities
    - Multi-modal interfaces

- A human-centered empirical approach:
- Define appropriate Human-Machine functional allocation
    - Start with a thorough empirical characterization of mission management activities in today's cockpit
    - In "no-comm" (autonomous) mode

Intelligent Spacecraft Interface Systems (ISIS) Lab Overview

Equipment

- 12 liquid crystal displays (LCDs) with touch screens representing
  - cockpit displays
  - side panels
  - overhead panels
  - keyboard
- A multi-platform computer network
- ISCAN ETL-500 eye tracking system
- Audio system
- An experimenter controller station

MET ~ 8.30

MM 103:
2nd Stage

MAIN ENGINE CUTOFF, EXTERNAL TANKS SEPARATION
Altitude:
59 nautical miles
Velocity: 25,581 feet per second about 8.5 minutes after launch (just before orbit insertion)

SRB SEPARATION
Two minutes after launch

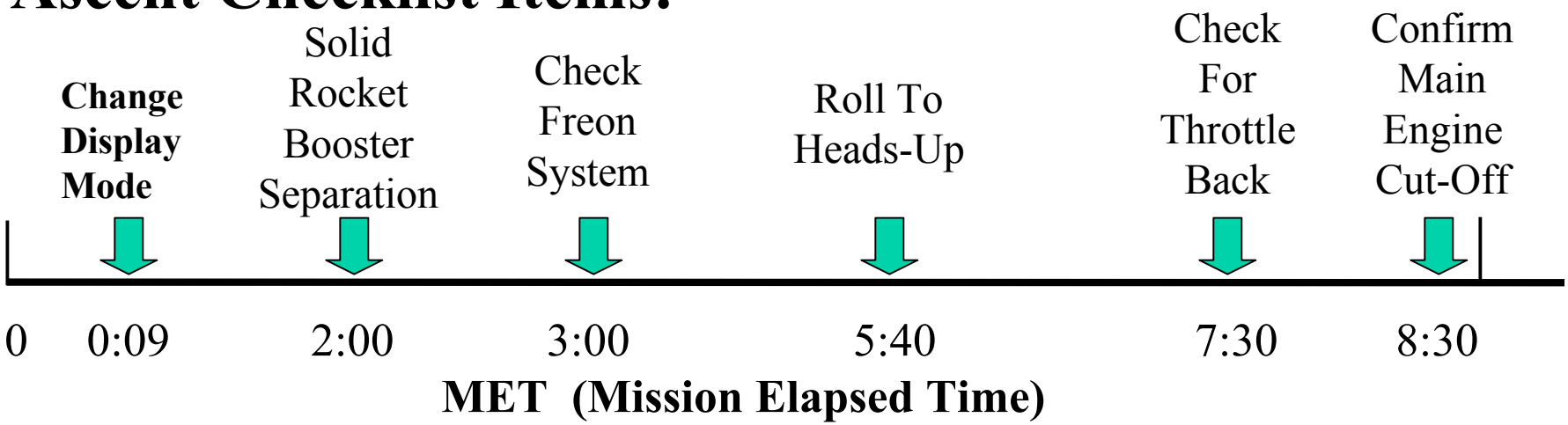
MET 2:00

MM 102:
1st stage

LAUNCH
Maximum dynamic pressure about 60 seconds after launch

MM 101 Prelaunch

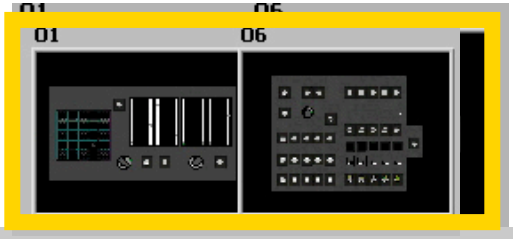
- **Ascent Checklist Items:**

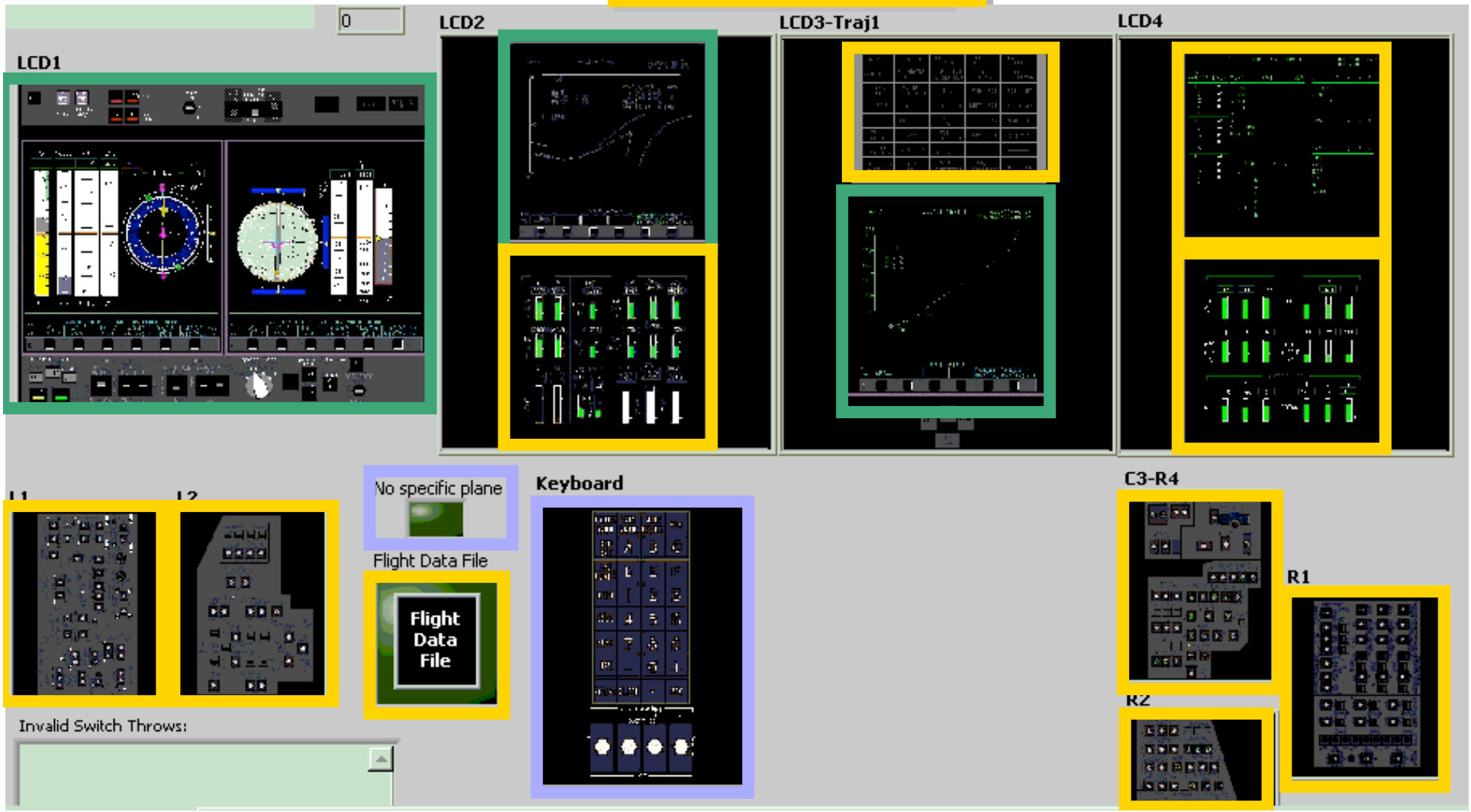


- **Continuous Tasks:**
  - **Check Navigation State:**
    - Trajectory, Velocity, Vertical Velocity, Attitude
    - Current Abort Options
  - **Check Systems Health:**
    - Main Engines:
      - Ullage Pressures
      - Helium flows

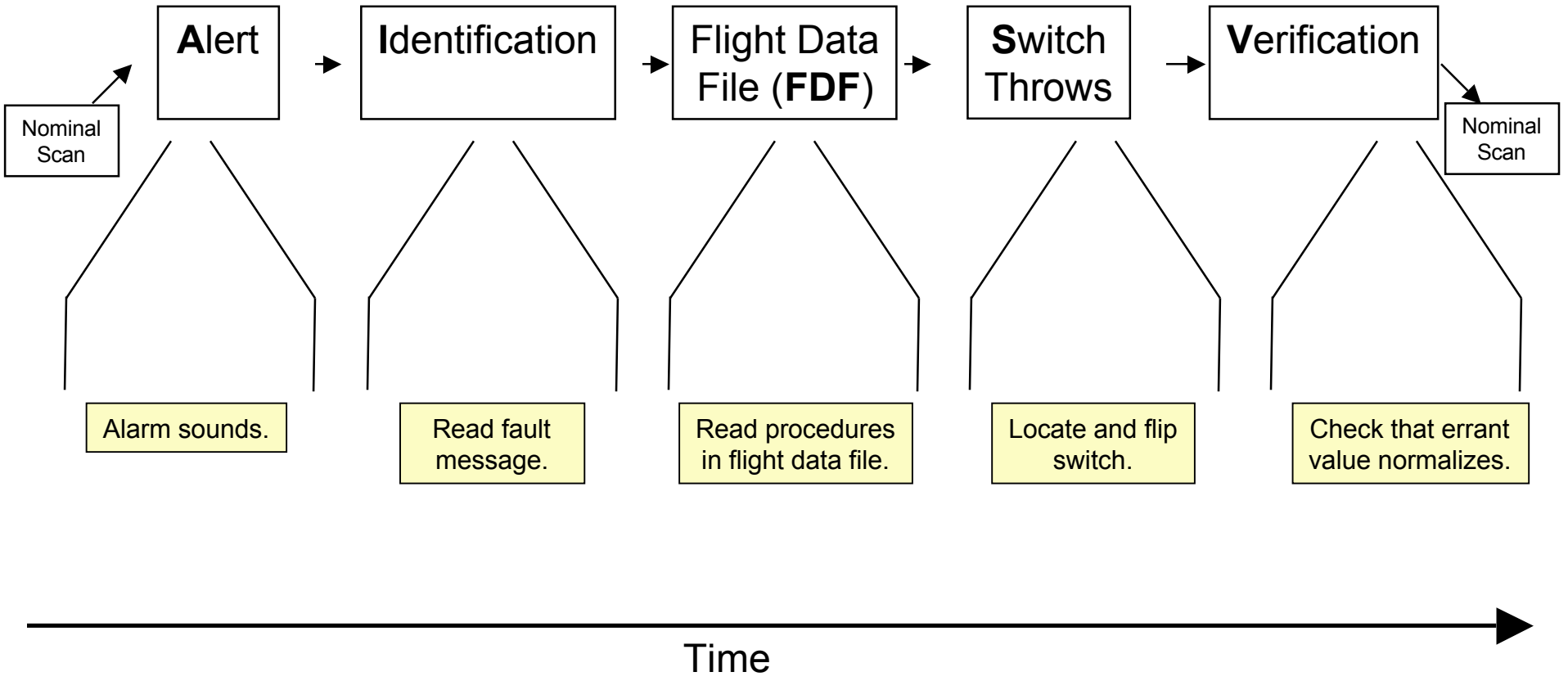
GNC Regions Systems

Neither

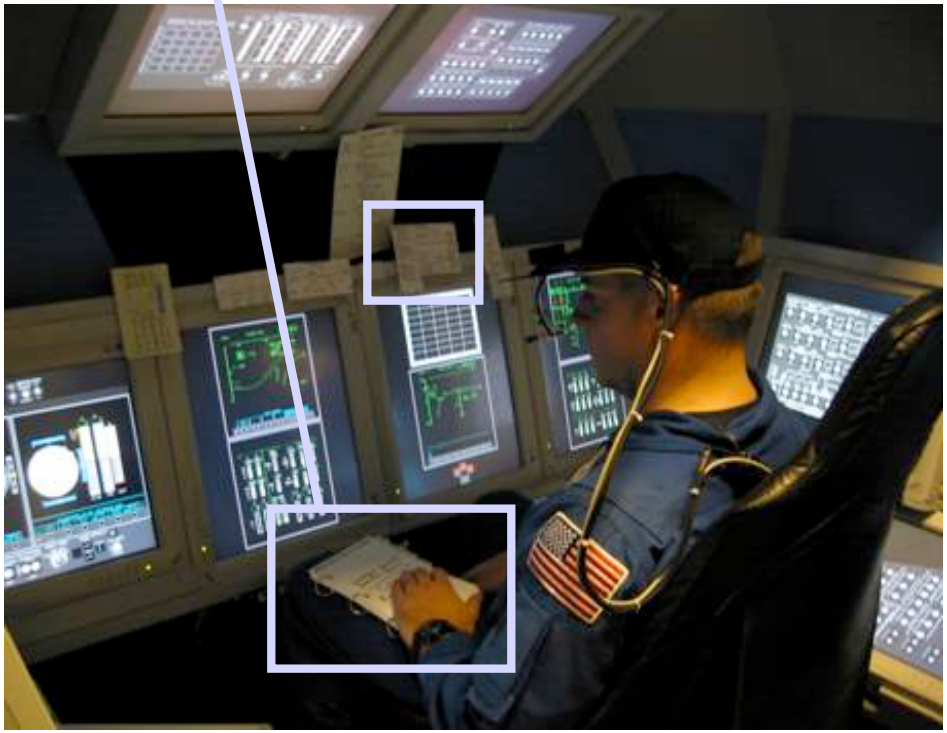




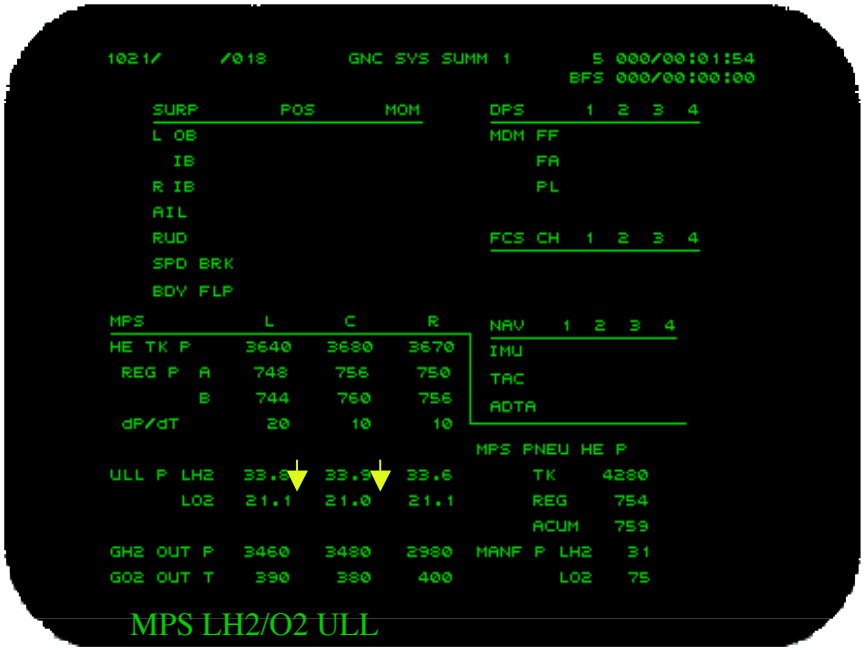
Fault Management Stages



"If 2(3) Ps < 31.6 or >34.5
MPS ULL PRESS - OP
When all Ps > 34.5
MPS LH2 ULL PRESS - Auto"

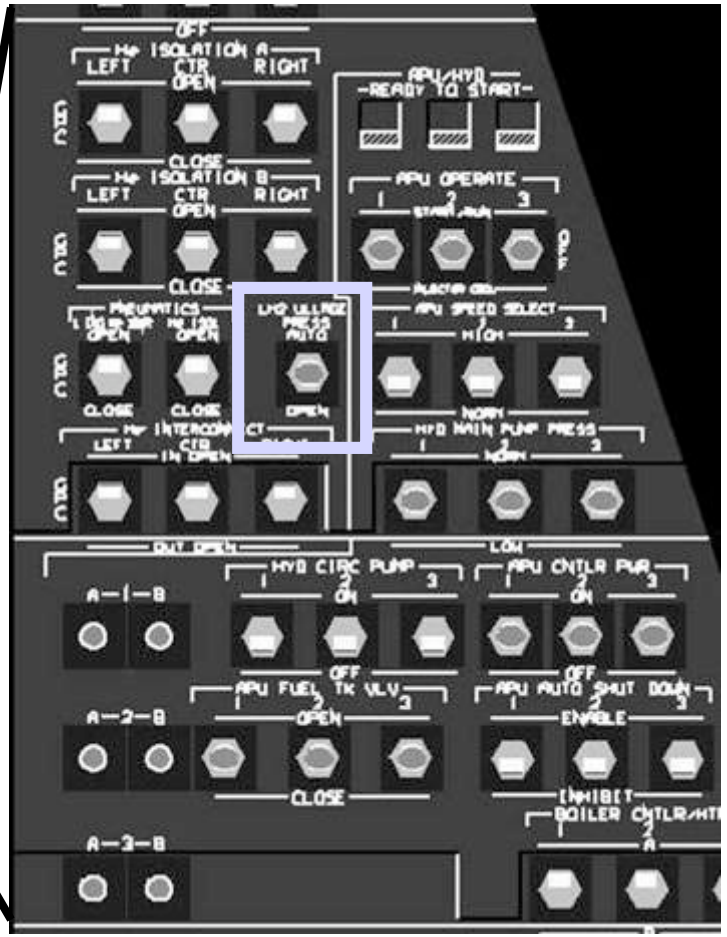


BFS GNC SYS SUM 1



MPS LH2/O2 ULL

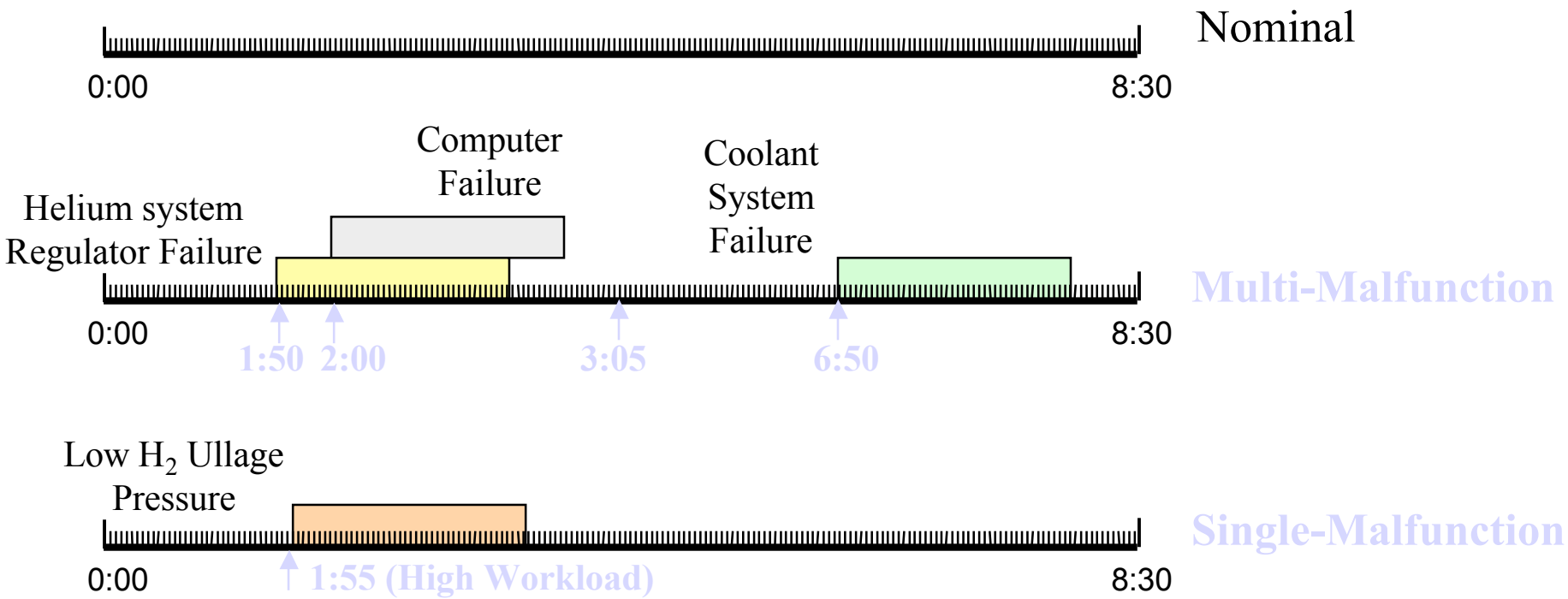
"If 2(3) Ps < 31.6 or >34.5
MPS ULL PRESS - OP
When all Ps > 34.5
MPS LH2 ULL PRESS - Auto"

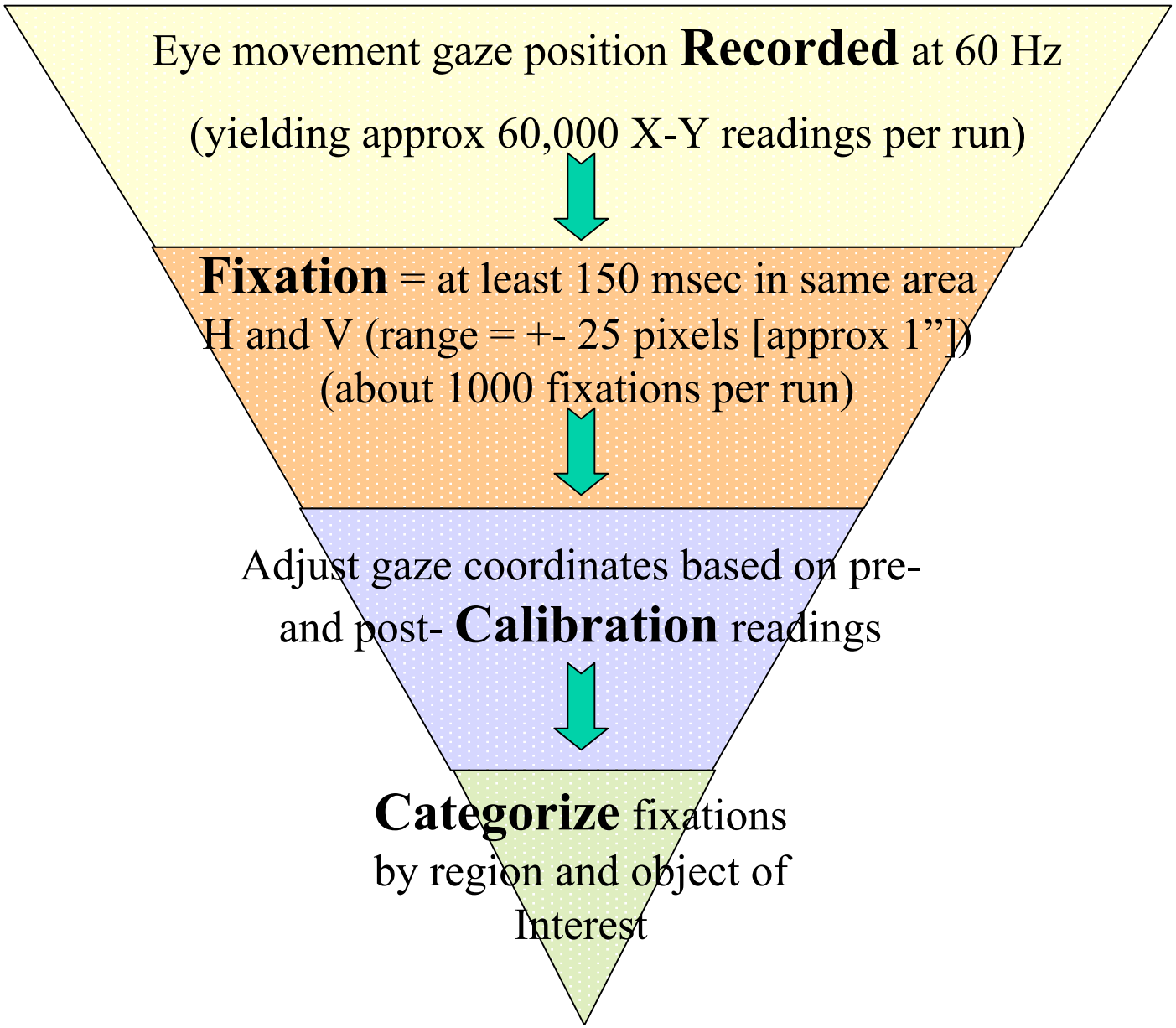


Experiment

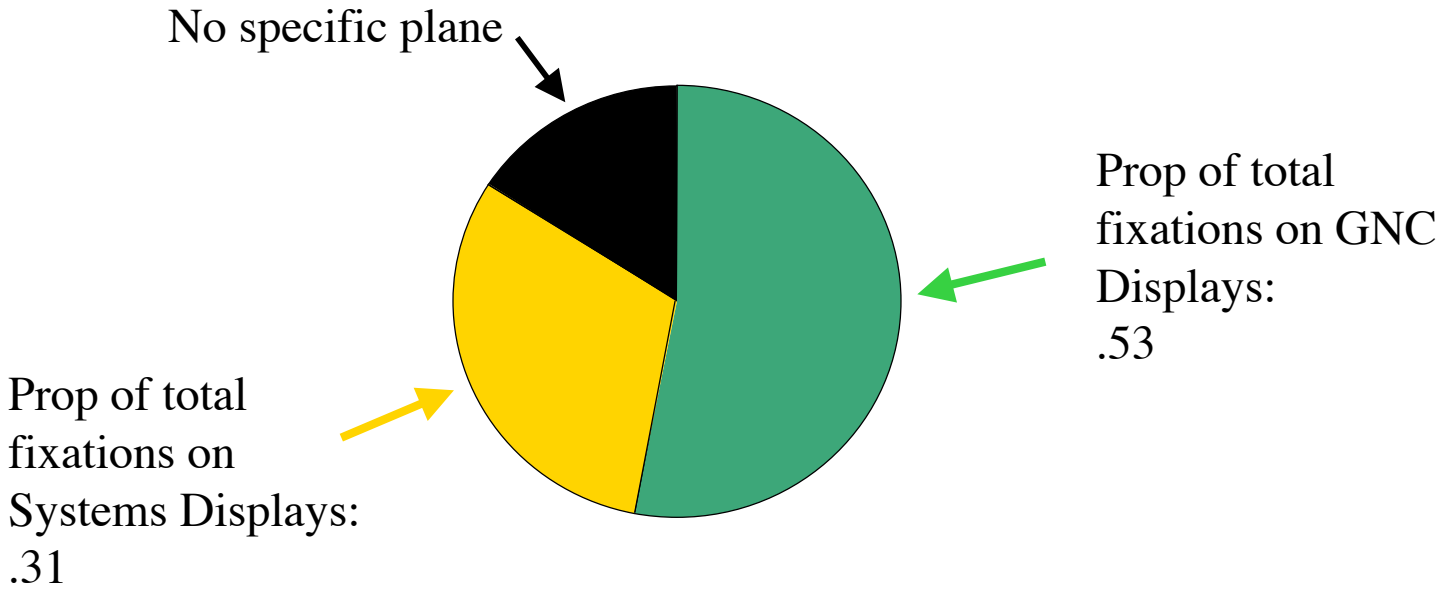
- Characterize and quantify nominal and off-nominal behavior in a task environment representative of current spacecraft cockpits.
- Demonstrate the validity of using eye movement measurements to infer multi-tasking strategies and characterize multi-tasking behavior.
- Compare behavior of “novices” (retired United Airline Pilots) with experts (Current Astronauts).

- 4 ascent runs per participant, each 8.5 minute in duration
- 3 types of trials: nominal runs, multiple-malfunction run, single-malfunction run

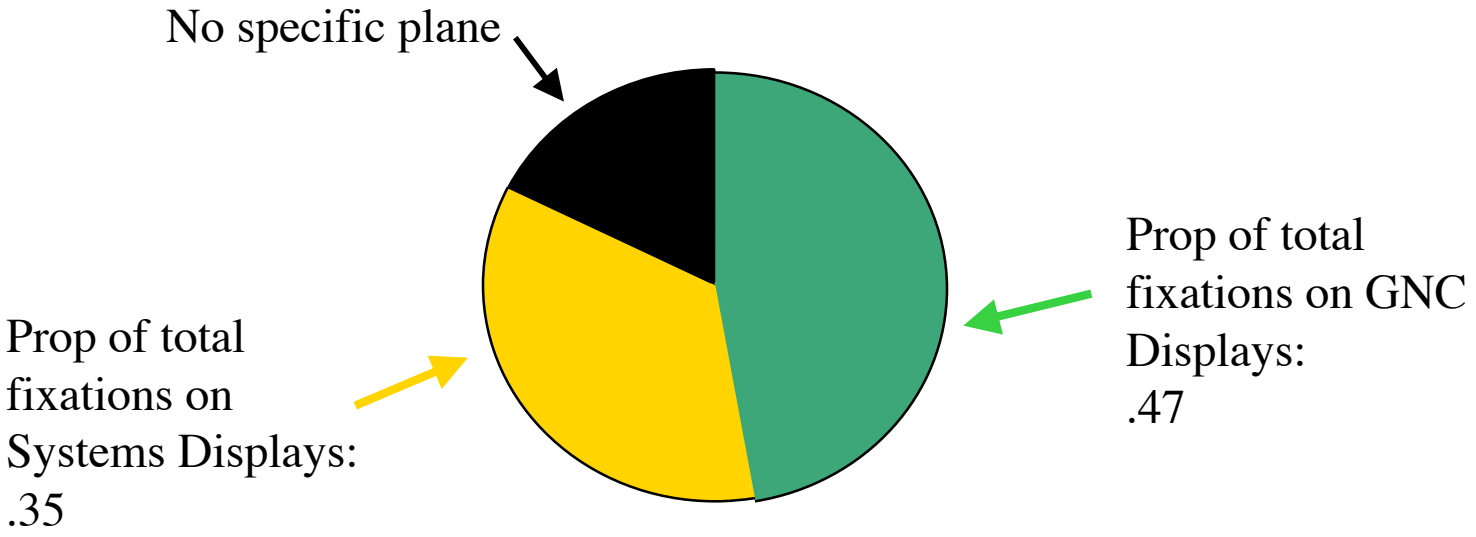



Eye movement gaze position **Recorded** at 60 Hz
(yielding approx 60,000 X-Y readings per run)
Fixation = at least 150 msec in same area
H and V (range = +- 25 pixels [approx 1”])
(about 1000 fixations per run)
Adjust gaze coordinates based on pre-
and post- **Calibration** readings
Categorize fixations
by region and object of
Interest

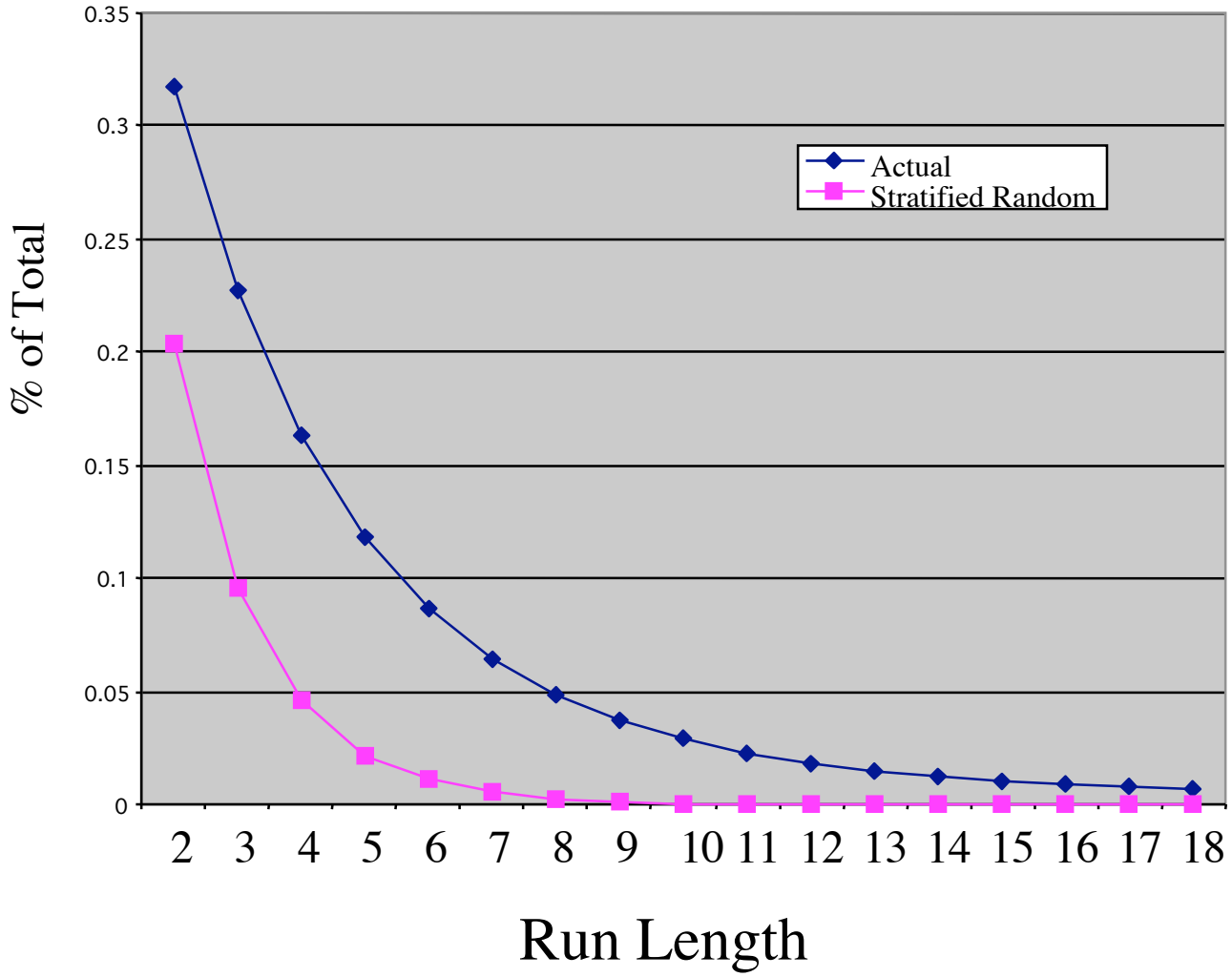
United Airline Pilots: Fixation Distribution

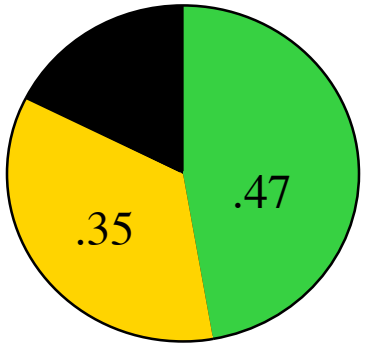


Astronauts: Fixation Distribution

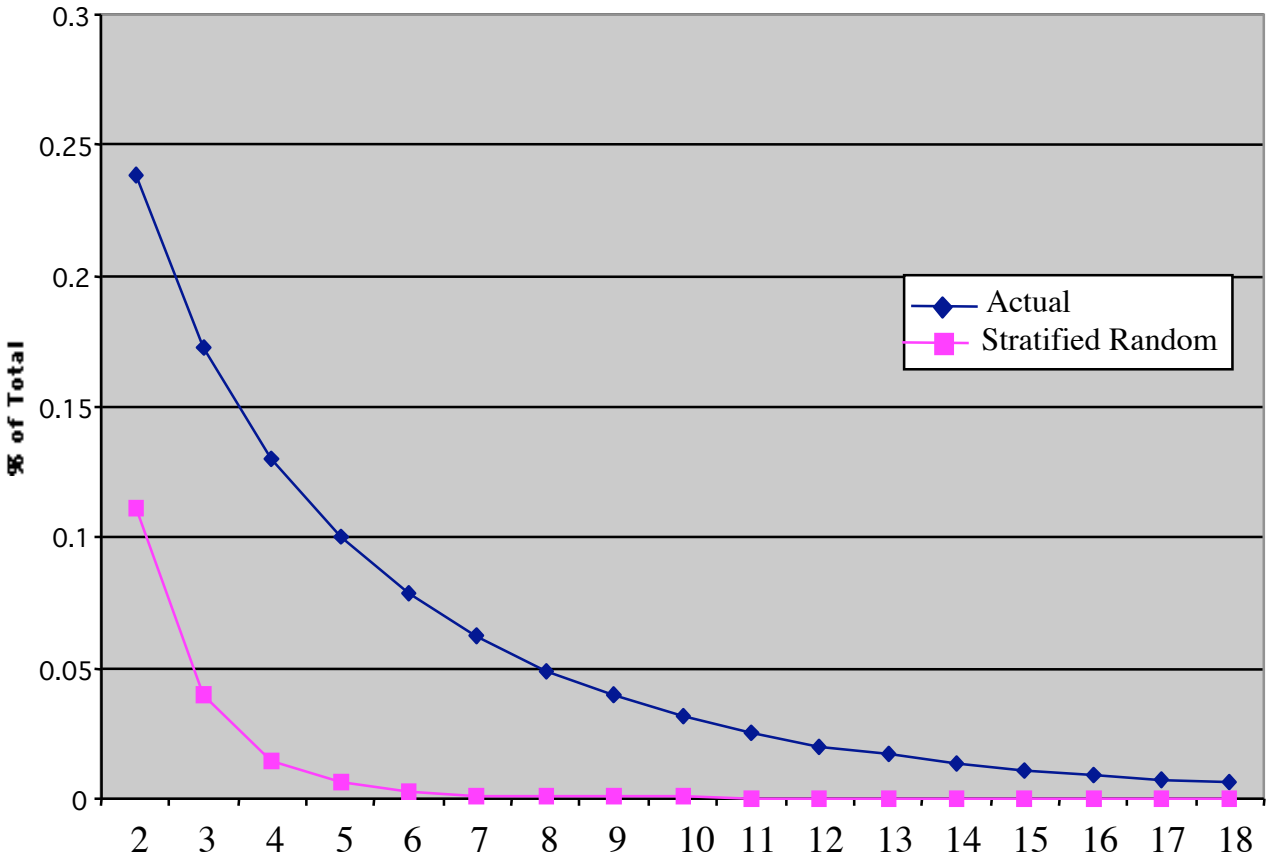


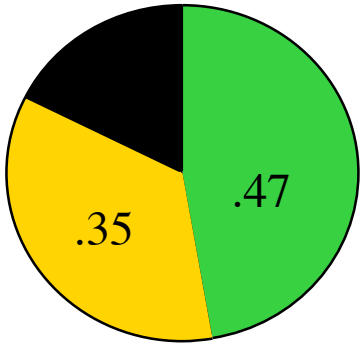
Sequences of Fixations on **GNC** Displays by **Astronauts**





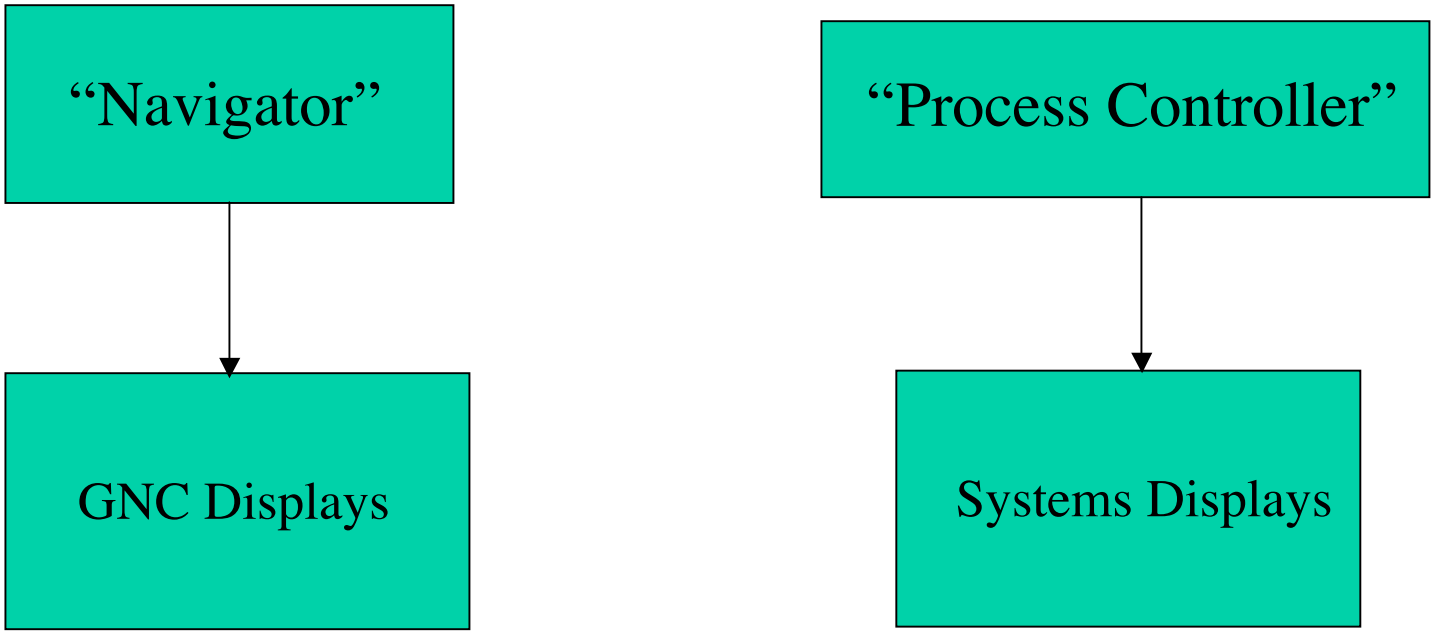
Fixation Sequences on **Systems** Displays by **Astronauts**



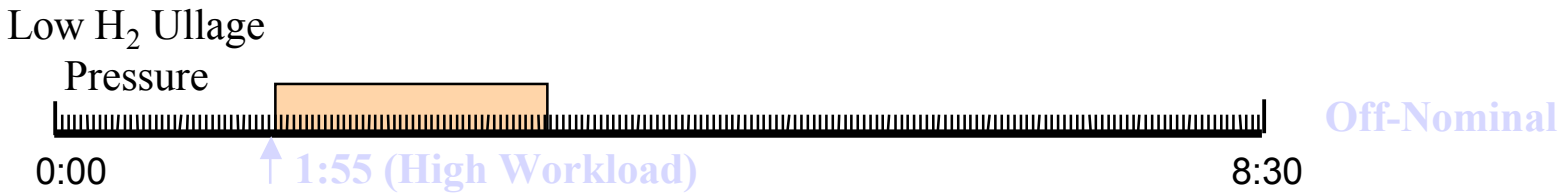


Information Acquisition Strategies: Nominal Runs

- Sequences longer than those predicted by stratified random



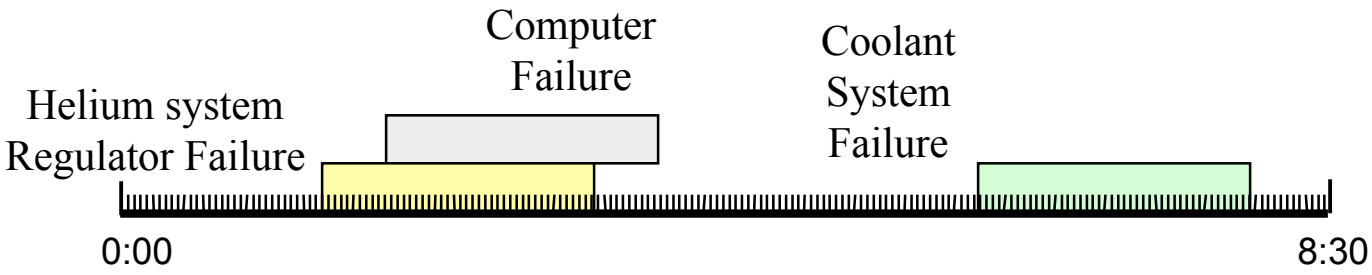
Performance Results for Single-Malfunction Runs



	Pilots	Astronauts
Procedures performed correctly:	4/5 (80%)	5/5 (100%)
Response time:	0:57	0:22

- Accuracy higher and response time faster better for the astronauts

- **Multi-Mal Run Results**



Helium Regulator Failure

	Pilots	Astronauts
Procedures performed correctly:	0/6 (0%)	5/5 (100%)
Response time:	"2:48"	2:48

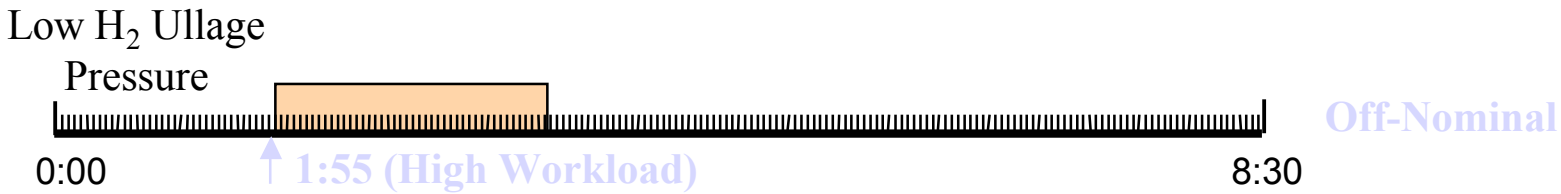
Computer Failure

	Pilots	Astronauts
Procedures performed correctly:	1/3 (33%)	4/5 (80%)
Response time:	2:49	1:31

Coolant Failure

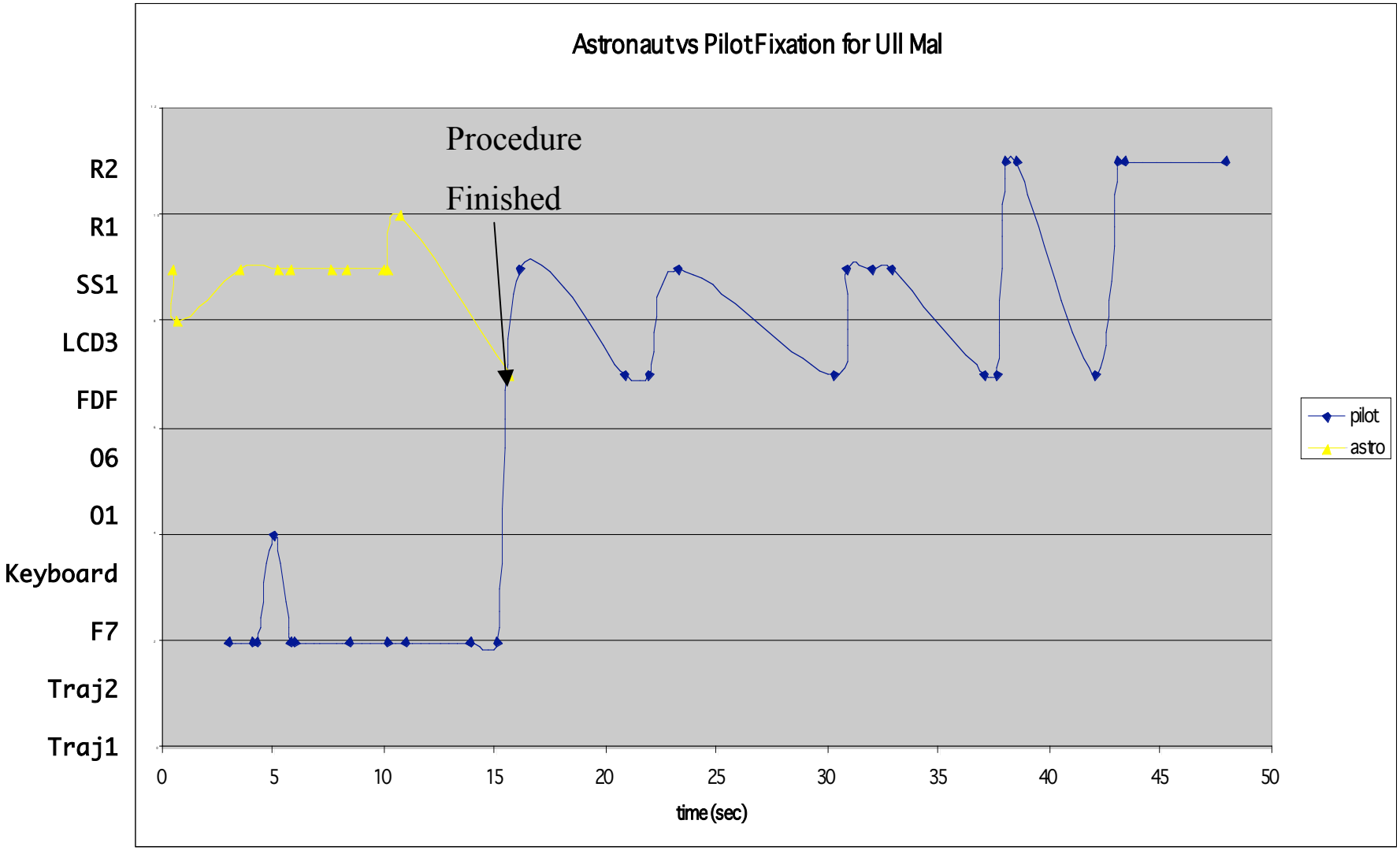
	Pilots	Astronauts
Procedures performed correctly:	2/6 (33%)	4/4 (100%)
Response time:	3:43	1:52

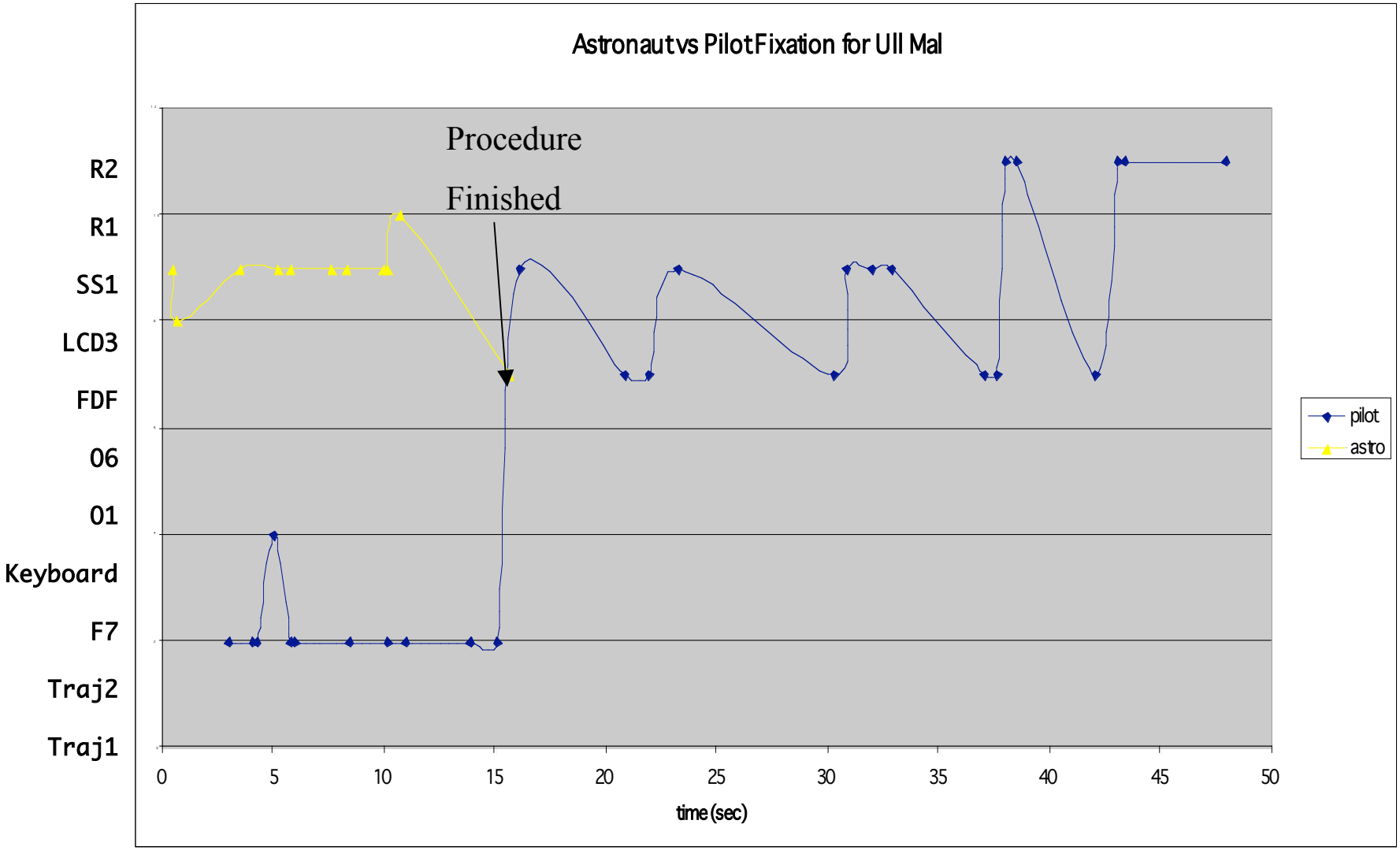
Performance Results for Single-Malfunction Runs



	Pilots	Astronauts
Procedures performed correctly:	4/5 (80%)	5/5 (100%)
Response time:	0:57	0:22

- Accuracy higher and response time faster better for the astronauts


Astronaut vs Pilot Fixation for Ull Mal
Procedure
Finished
R2
R1
SS1
LCD3
FDF
06
01
Keyboard
F7
Traj2
Traj1
0
5
10
15
20
25
30
35
40
45
50
time (sec)
pilot
astro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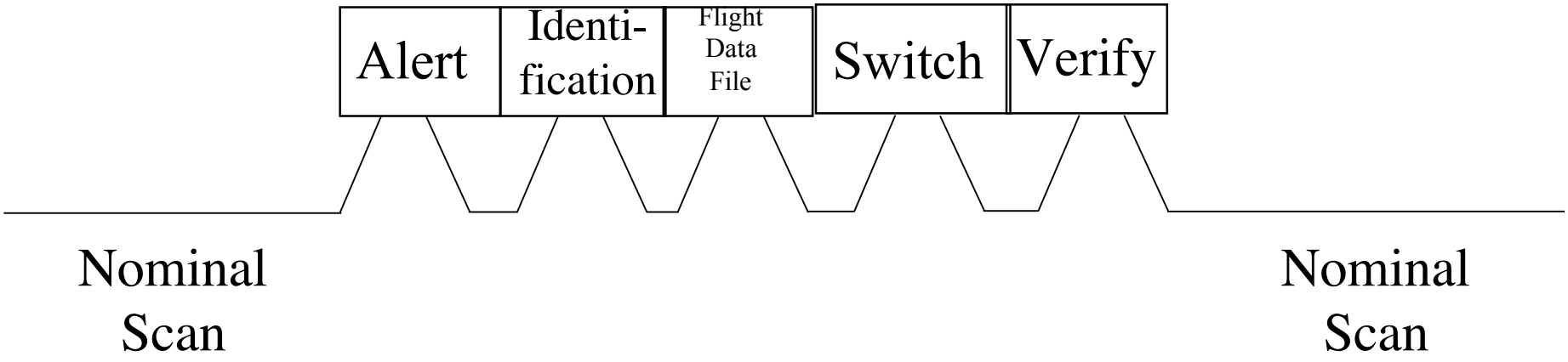
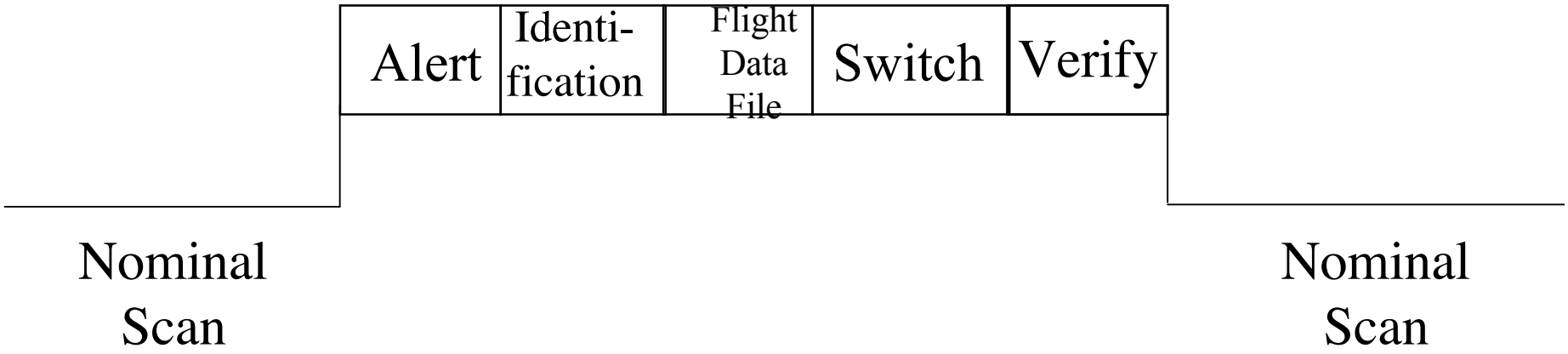
F7
Traj2
Traj1
0
5
10
15
20
25
30
35
40
45
50
time (sec)
pilot
astro

A Tale of Two Strategies

- Time Share: Divide attention between Fault Management and nominal scan

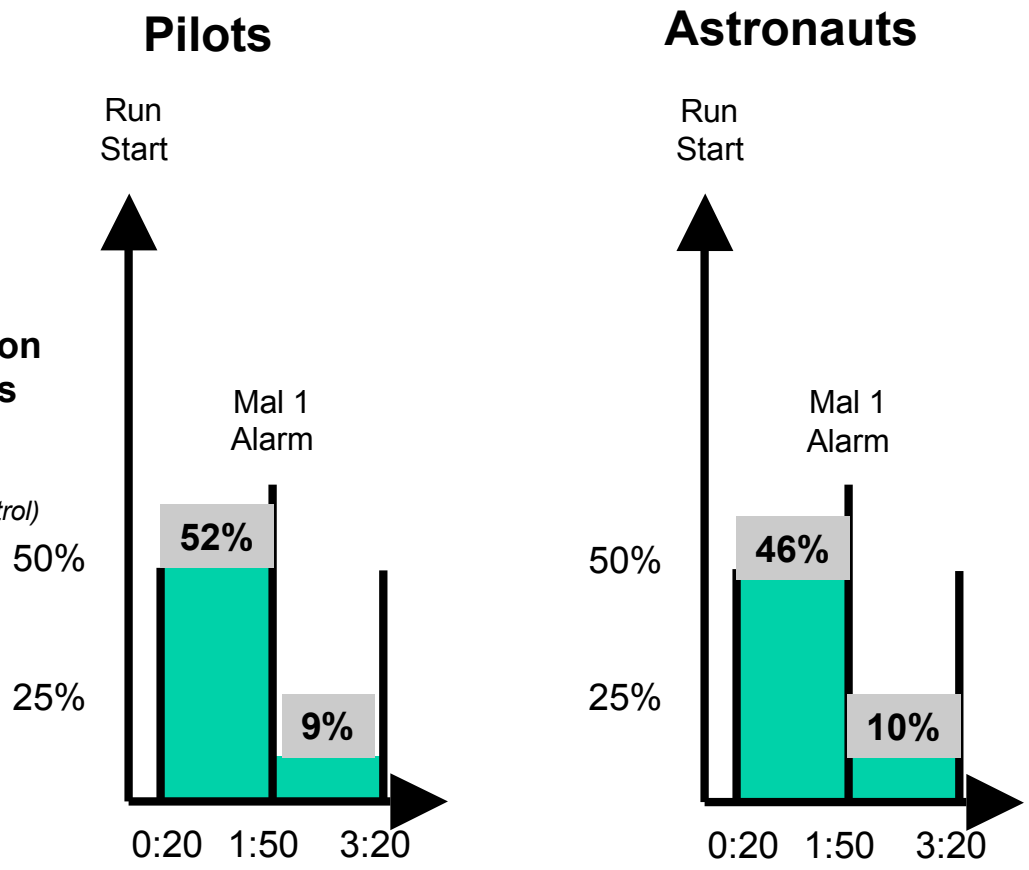


- No Time Share: Devote full attention to Fault Management activities



Fixation Time on GNC Displays

(GNC = Guidance, Navigation and Control)

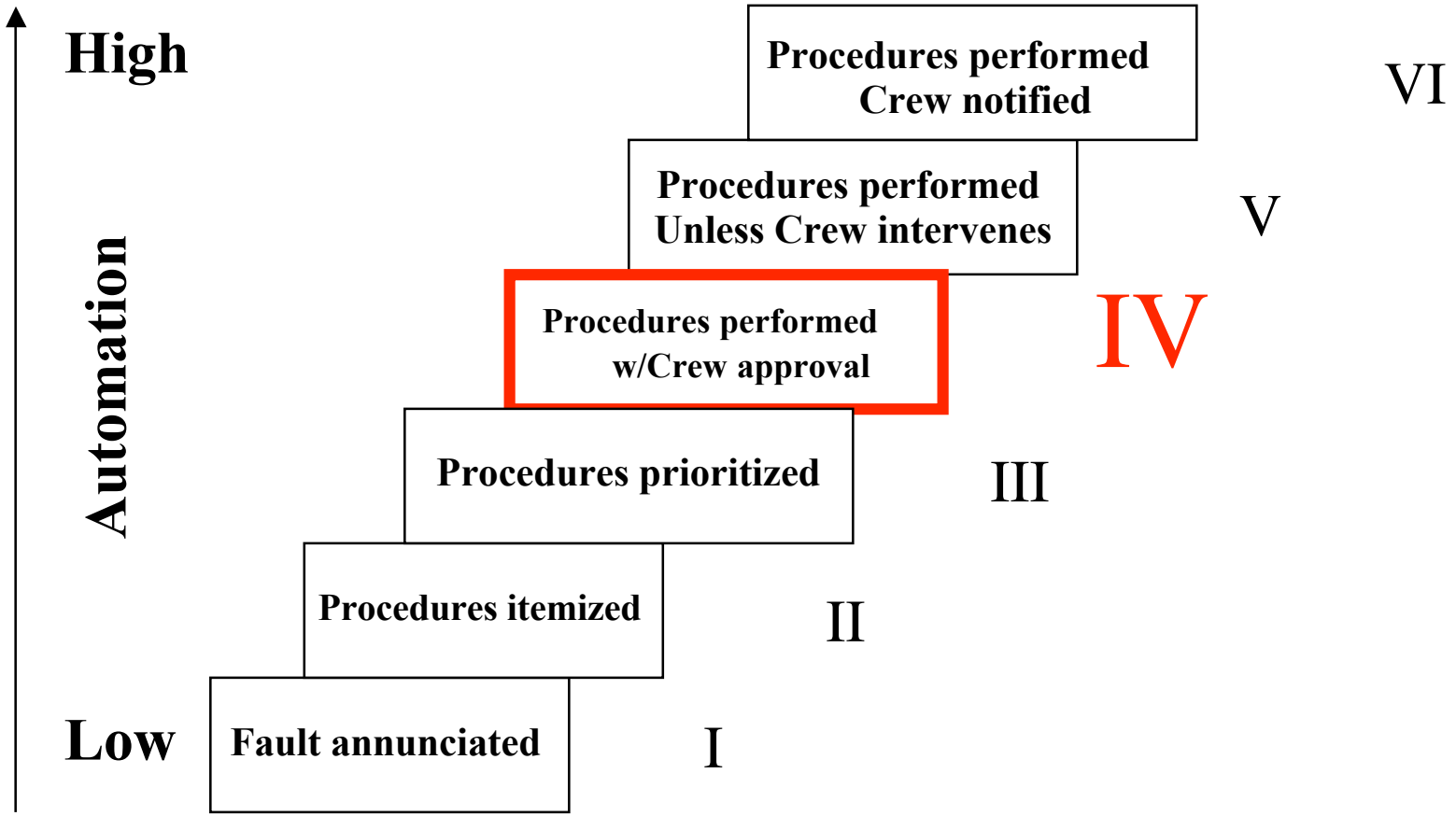


Mission Elapsed Time (MET) (min:sec)

Not to scale.

- Conclusions:
  - Nominal runs:
    - More attention to flight displays than systems displays
    - Participants shift back and forth between acting as
      - Pilots of a flight vehicle
      - Process controllers
  - Off-nominal runs:
    - Fault management causes:
      - Cognitive tunneling on fault-related information
      - Up to several minutes in duration
    - Primary fault management “time sinks”:
      - Reading flight data files
      - Locating cockpit switches

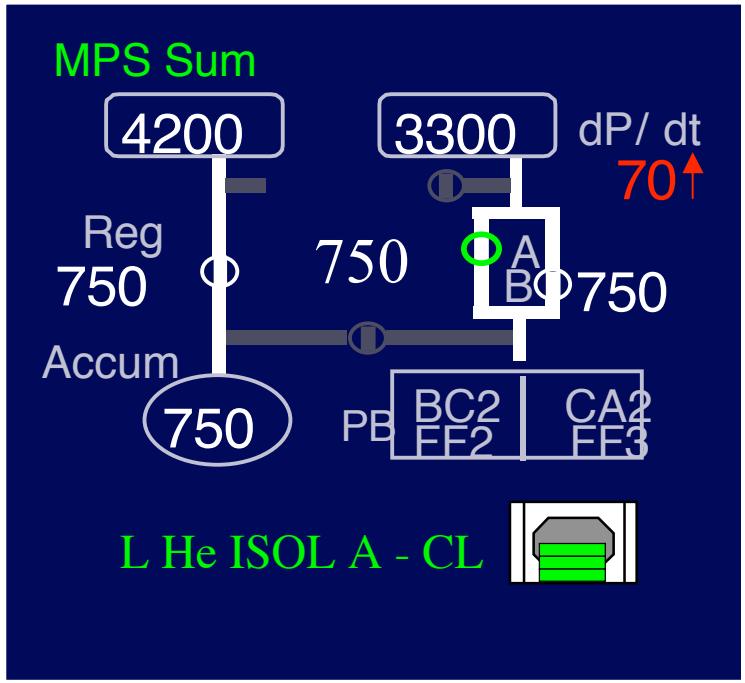
- Determine appropriate level of human-machine functional allocation (level of autonomy)



OPS Concept: HCI for Level IV automation

- Dedicated Malfunction Handling display:
  - Magnifies system area where fault exists
  - Procedures prioritized
    - Electronic flight data file
    - Green color coding
  - Virtual switch icon
    - Green switch position indicator

  Graphical reconfiguration cue
    - green valve circle indicator
- Permission: Physically touch green switch position indicator

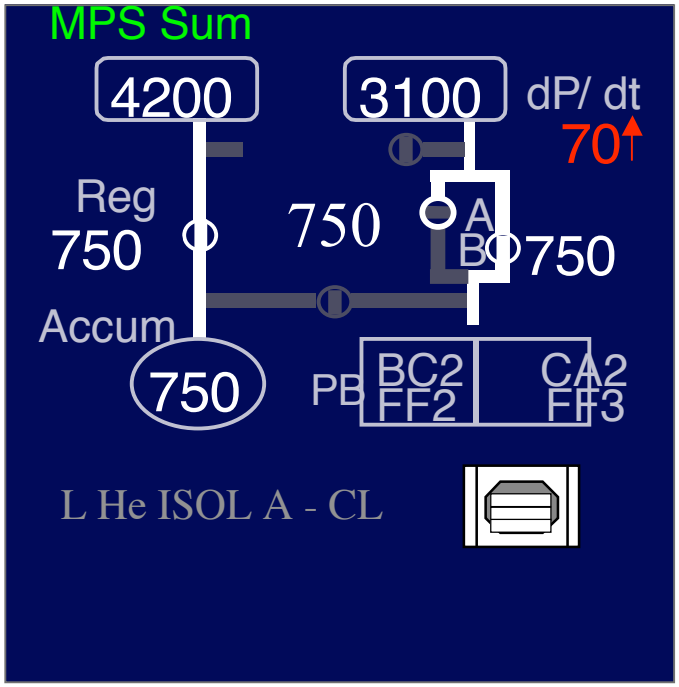


Step 1:

- Left helium isol valve A now closed

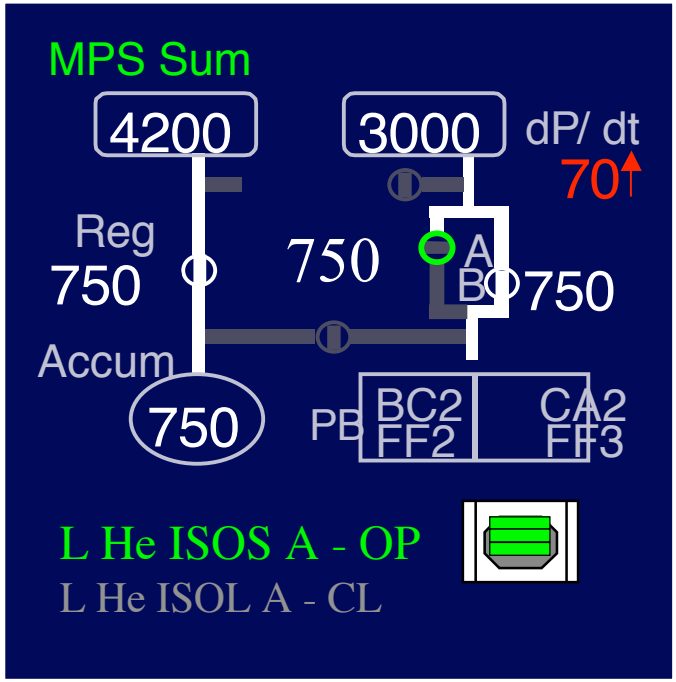
Flow through Leg A: gray (no flow)

- Text message turns gray
- Virtual switch:
  - Position indicator white
    - shows actual position (CL)
- Automation:
  - asseses system status
  - dP/dt still off-nominal high

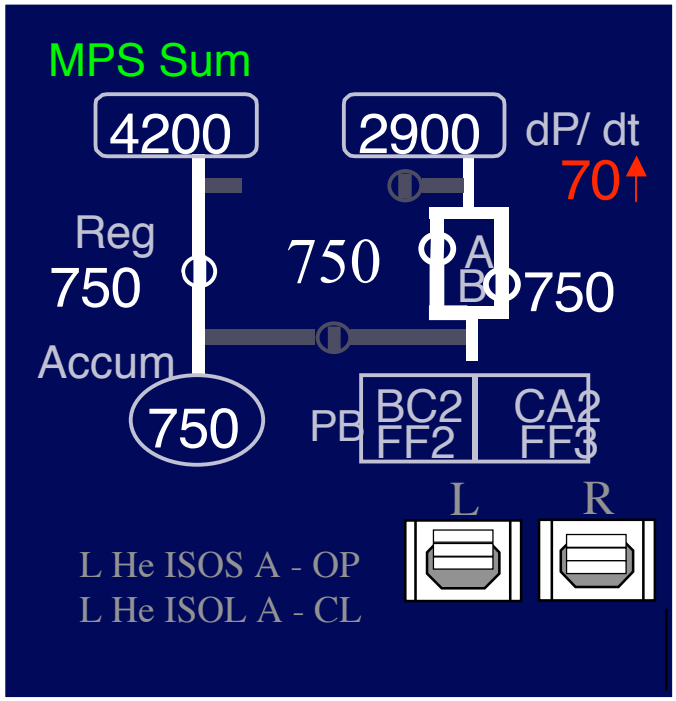


Step 2: Open Left ISOL Valve A

- Display indications:
- First procedural de-emphasized
  - (gray; moved down)
- New procedure in green
- Valve indicator green:
  - commanded state change
- Commanded switch position
  - Indicated, also in green
- Crewember:
  - touches commanded switch position indicator

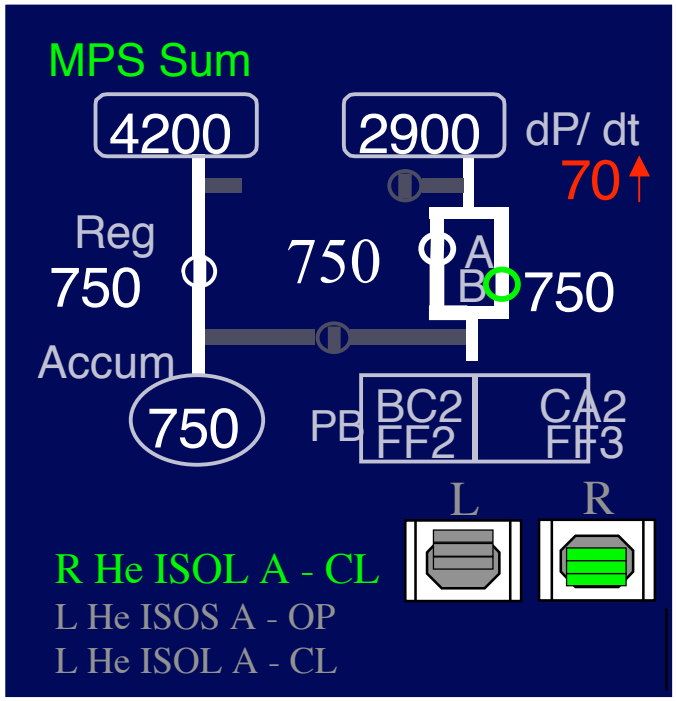


- System Status:
  - ISOL Valve A, B Open
  - dP/dt still indicating problem

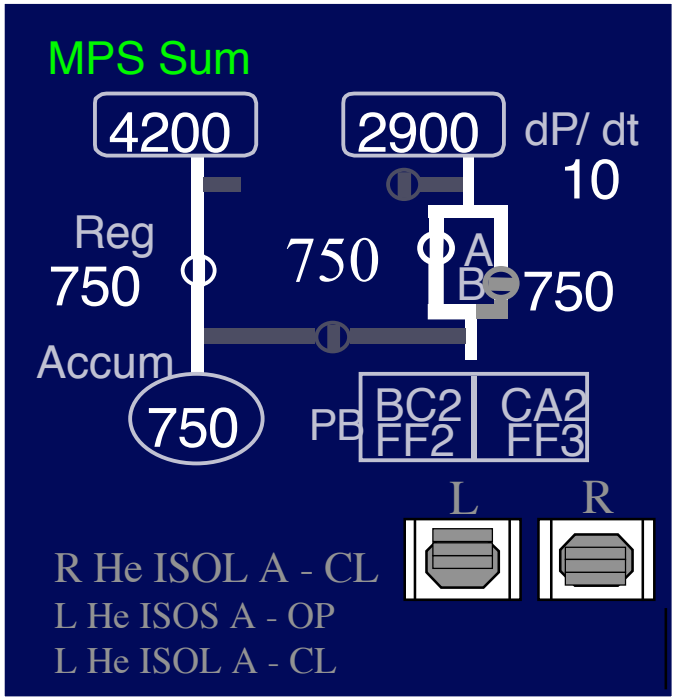


Step 3: Close Left ISOL Valve B

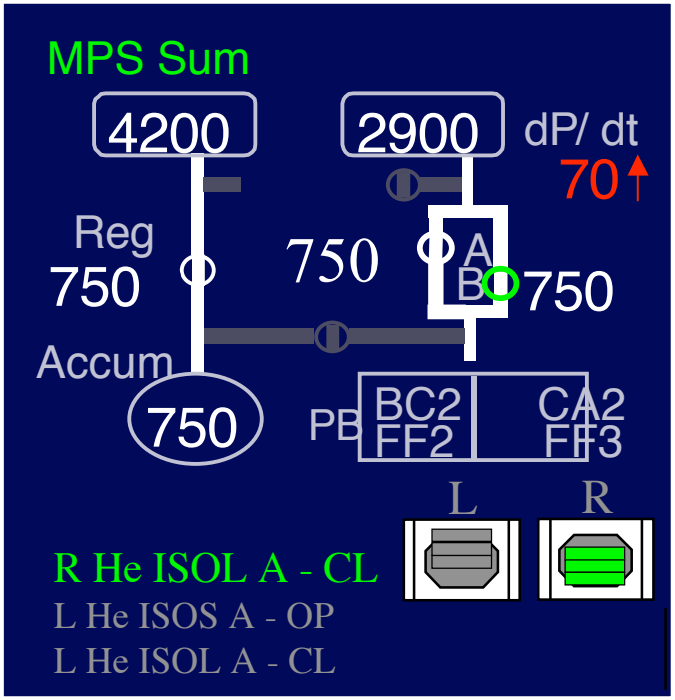
- Display indications:
- 2nd procedural de-emphasized
  - (gray; moved down)
- New procedure in yellow
- B Valve indicator yellow:
  - commanded state change
- Commanded switch position
  - Indicated, also in yellow
- Permission:
  - Crewember touches commanded switch position indicator



- Procedures complete:
- Display indications:
- dP/dt back to nominal color and value
- Final system/switch configuration shown

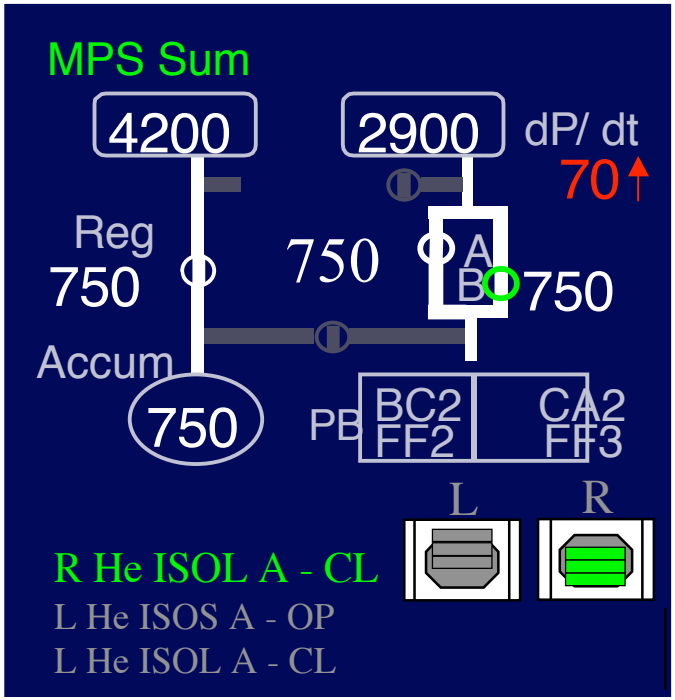


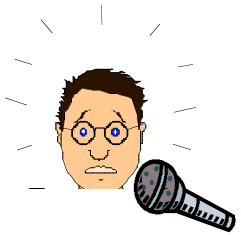
- Goal: Maximizing crew mission management capabilities
- Clear Limitation with Level IV concept:
- Virtually All human-system interactions are still visual-manual



- Grossly underutilizes available human information processing resources
- Multi-modal human-automation interface channels

"Right Helium Isolation A to Close"





"Proceed"

Future Directions

- **Near Term:**
  - Baseline measure of Level IV Automation Concept
  - First: visual-manual concept only
  - Then: visual-manual augmented with auditory-vocal channel
- **Far Term:**
  - Develop capability for multi-modal human-machine interaction in two crewmember cockpit